little more than daubs and splashes. This degenerate stage extended well into historic times, as was proved by the finding, in that horizon, of European objects, but before the final abandonment of the site there occurred a sort of renaissance, when glaze painting was given up and there was produced a yellowish pottery excellently finished and tastefully decorated with dull black pigment.

The details of this long ceramic history; the growth, for example, of vessel forms; the developments in the cooking wares; the influences from without that undoubtedly produced some of the changes; all these must await closer study and more data.

The stratigraphy of the site, then, throws invaluable light on the local culture; it also may be expected to teach us much as to its external relations. In the first year's work there has been found pottery of the historic period from the Hopi villages, Acoma, Zuni, and Jemez, as well as prehistoric wares from the Little Colorado, Lower Gila (?), and San Juan. From the East we have pottery, buffalo-scapula hoes and snubnosed scrapers; from the South, clay bells and spindlewhorls strongly Mexican in type. Such finds as these give an indication of what important results may confidently be hoped for. If we can definitely recognize and chronologically arrange the successive culture stages at Pecos, we can extend that knowledge and thus fit into their proper chronological order the one-culture ruins that abound in the Rio Grande. We may also hope to learn, from trade objects found at Pecos and in the chronologically arranged one-culture ruins, the relative age of many other groups, not only in the Southwest but even well beyond its borders.

MAN AND METALS

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In the course of a long-continued study of the uses of fire by man, I have recently completed a review of the branch referring to metallurgy, the results of which are embodied in the following brief summary.

The free metals which early man might have found and used are copper, gold, and silver. It is known that he used copper, and to some extent silver and gold, and that he worked them as other hard substances, becoming gradually acquainted with the property of ductility of these metals. Since copper was the most common metal in a free state and potentially at an early stage the most useful, it is safe to say that its employment was the beginning of the age of metals. Strictly,

the age of metals begins with the working of these naturally occurring substances by means of heat. The development of metallurgy has been the development of heat, resulting in remarkable inventions and achievements, and in the increase of temperature from that of the open camp-fire to the fierce heat of the blazing arc. Fire itself, the heritage of man through all ages, though adapted mostly to the advancement of man himself, had very limited use in the early periods, but the reactions of man on fire and of fire on man must have been profound.

Metallurgy is impracticable without a concentration of heat beyond that furnished by a fire in the open supplied with limited fuel. The first and natural step was to confine fire to a limited space demarked with stones or within a shallow earth-basin. Observations would show that the heart of the fire possesses greater heat than the margin and in an especially hot focus, one day when the time was ripe, a metal, likely copper, was tried and was found to melt and run without losing its structure. From such an event as that fancied here metallurgy may have had its crudest beginnings. The objection is noted that copper which liquidifies at 1083°C. would not melt ordinarily in an open-hearth fire under natural draught and this will be commented upon later in describing the efficiency of a smothered fire massed in an earth pit. Early experiments however were far from an established practice of metallurgy, a vast time may have elapsed before metals could be reduced from the ores. The history would begin with free metals regarded as stone and continue with metals (copper) hammered into shape; smelting of free metals (copper), and casting, followed by work in combined stone and metal technique; alloys both adventitious as in tin-bearing copper and designed as in the addition of cassiterite or oxide of tin to copper producing bronze.

This imperfect résumé covers a great advance in heat production to the time when a fourth metal, tin, becomes known to man. The bronze age with its ramifications of art, of science, and of material and social progress can only be characterized as a period when the cruder tentative essays in metals were brought to a somewhat exact metallurgical formula of pre-science. The Bronze Age also illustrates the vast importance of alloys. It more especially marks for the purpose of this paper the production and regulation of heat sufficient to smelt copper and tin forming the alloy known as bronze.

It may be possible to trace the steps by which this heat was reached and it seems probable that its attainment depends on some other use of fire rather than for metallurgy. In this regard attention is called to the confinement of fire in a primitive oven for baking pottery or the

cooking of vegetal substances, both very ancient arts and nearer to early needs than the working of metals. The cooking of vegetables in its primitive stage gives rise to ovens which may be ancestors of the furnace for reducing metals, namely the pit or 'gipsy' oven in which refractory fruits and vegetables were cooked. These pits were dug in the earth and heated by burning fuel in them, the coals removed and the vegetables put in and covered up, a fire often being set on top. It is observed that in modern instances the heat produced by a fire of this character is very great at the bottom of the glowing coals. There is a great concentration of heat due to the confinement of the fire in a non-conducting medium and this effect does not depend greatly upon excess oxygenation of the fuel by draught, in fact too much draught cools a fire. In such a fire bronze may easily be melted. There is used to this day a pit-smelter for melting bronze and this device would seem to be a survival. I saw one of these ovens in use in Washington a few years ago where it was employed for melting small portions of bronze for minor castings. European discoveries indicate that bronze was melted in pits in the earth and that the bronze founders had also acquired a knowledge of refractory clays which may have been contributed to some extent by the potter's art. It is evident that clay and metal working are intimately connected.

The production of higher temperatures depends upon the oxygenation of the fuel beyond that ordinarily furnished by natural draught. Natural draught in a forced fire fed with abundant fuel may give a central area of high temperature, but the question of fuel supply would militate against the common employment of this method. The simple way in the earlier periods would be to aerate the fire with a fan-like hand-blower such as are used with the braseros and small cooking fires in many parts of the world. There would follow other devices to produce draught, culminating in the modern tremendous mechanical development for forced draught. Some steps on the way may be observed in the aboriginal pit ovens for cooking previously mentioned. Most of these are without draught holes or any device for producing draught, depending for their utility upon the absorption and retention of heat in the earth wall of the pit. The pit ovens of the Pueblo tribes have a draught flue alongside the pit. A step in advance involved in building separate fire containers is the raising of the fire and the production of bottom draught. To forced draught however we must look for practical advance in metallurgy, and in comparatively recent times the use of preheated draught or blast was epoch making in the science of the production of metals. The forerunner of this was the tuyere embedded beneath the fire.

The knowledge of metals in the Bronze Age was confined to those native metals, copper, gold, and silver, and of reduced metals tin and possibly lead. The development of temperature in the Bronze Age paved the way for the reduction of iron, the most important metal known to man.

In general no extensive reduction of ores could be attained with the facilities of the Bronze Age. It is improbable that much copper ore was reduced in this age, the source of supply being nuggets of native copper. Tin in the form of the oxide resembles a native metal and would attract the attention of man. It is easily reduced at a moderate heat and requires no roasting or flux, but whether this had any bearing on the discovery of bronze is not clear. The combination of copper and tin presents no difficulties since both metals are easily accessible and of wide occurrence. Native copper containing tin and forming a natural bronze is known, but is rare and had no effect on the discovery of alloys. Copper alone is very difficult to smelt and cast so that there is no very definite copper age and not many cast artifacts of this metal have been found. The copper age would be the period when native copper was shaped by hammering as especially in North America. Bronze may have resulted from experiments with mixtures of various substances to lower the melting point and to admit of casting in a closed mould. As a rule ores consisting of oxides of metals presented little difficulty in smelting. Carbonate ores could be oxidized by roasting before smelting following the old process. The chief difficulty in the reduction of ores is due to the presence of impurities chiefly sulphur and phosphorus which remain the bane of modern metallurgists. Another difficulty is the kind and proportion of flux. The question of fuel was not pressing, charcoal being the usual and immemorial supply up to the use of coal.

The niceties of the reduction of ores remained for modern science, early metal workers confining their attention to varieties which could be reduced by the facilities and knowledge in their possession. It is possible that the bronze age even at its focus may have overlapped the iron age and it is not strange that some students should have been led to assert that iron preceded bronze. The accumulated knowledge required for the reduction of an inconspicuous ore to secure a metal not known in a free state and with properties and value unknown is greater than the production of an alloy of two metals one free and the other practically free and both known to man for untold generations. There are also the high temperature, 1200–1300°C., and the experimental data on fluxes required in the reduction of iron ore. The metallurgy of iron was a distinct advance on that of bronze and made use of the ex-

perimental knowledge and mechanical equipment acquired in the bronze age. The bellows which classical writers attribute to Daedalus and Anacharsis may have made possible the reduction of copper ores in the later bronze age and may have unlocked at another period the coming metal iron.

The Iron Age, which began before the dawn of history, ushered in the fifth metal whose effect on the material world was destined to be incalculable. Man had seen metallic iron derived from meteorites and there exist implements made from this material, but its occurrence was sporadic and limited, so that it had no effect on his arts. Heavy and lustrous hematite ores were also widely used for implements and ornaments. When and in what locality iron began to be smelted is unknown, but as has been stated, it is the logical successor to the advanced technique of the metallurgy of bronze. Primitive iron working may still be observed in Africa and has been described in India. African ore is an oxide comparatively very easy of reduction and ore beds are of general occurrence. The smelter consists of a basin-shape depression in the ground beaten down hard and leading to the center is a clay tuyere with which the rude bellows are connected. The ore is heaped with charcoal in this depression and in the midst lighted coals are placed and covered over. The bellows are started and after a time the ore is reduced to a fluxed mass in which small pellets of iron are found. The mass is pounded up and the iron sorted out to be hammered into larger pieces by a second process. This was essentially the method pursued in India. Only limited amounts of metal were secured. Casting of iron was unknown in Africa. The knowledge of smelting is quite diffused in Africa so that there are no chief centers of manufacture and distribution, although some tribes are famed as blacksmiths and a few tribes depend on alien artificers for their iron utensils. The smelting of iron ore is impossible without forced draught. The bellows therefore is a device of great interest and importance. The history of draught-producing devices embraces the hand fan, the tube for blowing, the air bag in which the air is captured and forced out by pressure through a tube, the double air bag to promote a steady stream of air, the double air bag worked by rods, in which a valve appears, the double plunger bellows, the piston bellows, the folding bellows with organ valve used by blacksmiths before the invention of the fan blower, and the fan blower which brings back the primitive hand fan much improved.

The most marked types, the complete knowledge of which would cast much light on the history of Western and Eastern foci of metallurgy, are the air bags and piston blower the former belonging to the Europe-Africa province and the latter to Malaysia.

Furnaces also have an instructive development. There may be cited the rudimentary heap-furnace with base draught and rude bellows; the pit furnace for melting bronze with fan draught; the prehistoric earth wall furnace for reduction of copper and iron ores probably with bellows draught; and the tall furnace built of masonry and called Catalan furnace with means for forced draught.

The furnace of the Iron Age has been well described by archaeologists for northern France, Switzerland, Austria and other localities in Europe. On account of convenience they were located on the vein of ore and in forests which would furnish charcoal. The furnace consisted of a pocket excavated in the side of a clay bank lined with clay and, when charged, covered with clay leaving a flue above and draught hole below. The ore and charcoal were packed in layers and the draught was probably supplied with rude bellows.[1]

There is a considerable history, which may only be indicated, in regard to the tools required in metallurgy, as those for handling—pincers, tongs, shovels; for shaping—hammer, file, rubbers, polishers; for casting—crucibles with supports, handlers and poker-stirrers, moulds of stone, metal, clay and artificial mixtures; for finishing—file, abraders, polishers, punch, drill, chisel, rivets, etc.

At some period in the Iron Age it was discovered that iron could be cemented or case hardened by reheating with organic materials away from air, the process forming a layer of steel over the softer iron or, if continued, converting the whole mass to steel. In some localities, possibly India, at remote times metallurgical processes had given rise to steel. This new alloy could be tempered, a quality foreign to any other metal known to man. Up to comparatively recent times however steel had a limited use, but at present among civilized nations steel is more common than iron.

An interesting survey is presented of the state of metallurgic art in the various world areas. It shows that the Pacific Islands, most of the Americas, Australia, and much of Asia are in the premetallic stage; Malaysia is in the beginning of the metallic age by acculturation, the first demand being weapons; native Africa is advanced in iron metallurgy, using two metals; civilized (Mediterranean) Africa advanced in the use of metals; Europe (Mediterranean) shows early development and use of five metals. There are four great ancient foci of metallurgic art; Southern Europe, Northern Africa, Western Asia, and Eastern Asia. The latter is of doubtful origin and affiliation, but the other foci were connected. American foci are Central America, Mexico, Peru, and Wisconsin.

Ancient man beginning with one important and two minor free metals acquired by heat tin and iron giving him an acquaintance with five metals. Modern man has freed 52 more, knows 85 elemental substances and predicts the eventual discovery of several others.

[1] Rollain, A., Scories de fer antéhistoriques., *Bull. Soc. Anth., Paris*, 4 s, 1899, p. 318. Discussion by M. Lionel Bonnemère.

ON THE OBSERVED ROTATIONS OF A PLANETARY NEBULA

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The geometric forms of certain classes of nebulae are such as to suggest that they are in rotation about axes passing through their effective centers. We refer especially to the spiral nebulae and to those so-called planetary nebulae which are of ring, circular, or elliptical form with relatively condensed or stellar nuclei.

In the latter part of 1915 we tested several planetary nebulae by means of observations made with the Mills 3-prism spectrograph and obtained positive evidences of rotation, as Doppler-Fizeau effects.

The planetary nebula No. 7009 in Dreyer's New General Catalogue, right ascension 20h. 58m., illustrated herewith, was submitted to the test of four spectrograms. In each case the slit of the spectrograph was placed centrally across the image of the nebula and made slightly longer than the diameter of the elliptical outline of the nebula, and the condensed nucleus of the nebula was kept central in the slit during the exposures. In two exposures the slit was placed upon the longer axis of the nebular image, parallel to the slender rectangle drawn above the nebula in the illustration to represent the slit in length and direction. In a third exposure the slit was placed east and west across the image. On these spectrograms the bright lines of nebulium (4959 and 5007A) and of hydrogen (H Beta), comprising the recorded nebular spectrum, were inclined to the 'zero' direction, as indicated by the comparison spectra of hydrogen, helium and titanium on the same plates. This inclination of the lines is illustrated (exaggerated) by the direction of the bright line on the diagram of the slit in the upper part of the figure. The section of the lines corresponding to the western parts of the nebula are displaced to the violet, and the sections corresponding to the eastern parts, to the red. Interpreted as Doppler-Fizeau effects, the western parts of the nebula are approaching us and the eastern parts are receding from us by virtue of the rotation of the nebula. The fainter ends